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Krah

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(54) **FEED-IN/FEEDBACK CONVERTER WITH PHASE CURRENT TRANSFORM**

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(51) **Int. Cl.**

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H02M 7/539	(2006.01)
H02M 7/219	(2006.01)
H02M 1/00	(2006.01)
H02M 1/084	(2006.01)

(52) **U.S. Cl.**

CPC ***H02M 7/53871*** (2013.01); *H02M 1/084* (2013.01); *H02M 7/219* (2013.01); *H02M 7/539* (2013.01); *H02M 2001/0003* (2013.01); *H02M 2001/0025* (2013.01); *H02M 2007/53876* (2013.01); *H02M 2007/53878* (2013.01)

(58) **Field of Classification Search**

CPC H02M 7/53871; H02M 2007/53876; H02M 2007/53878

See application file for complete search history.

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(57) **ABSTRACT**

A method of controlling a frequency converter comprises steps for measuring phase currents flowing in a three-phase supply network, for generating a first modulation space vector that comprises an angle that is synchronous to a supply voltage of the three-phase supply network and a determined modulation index as an amplitude, for generating a third modulation space vector depending on the first modulation space vector and the measured phase currents and for modulating the frequency converter according to the third modulation space vector.

7 Claims, 9 Drawing Sheets

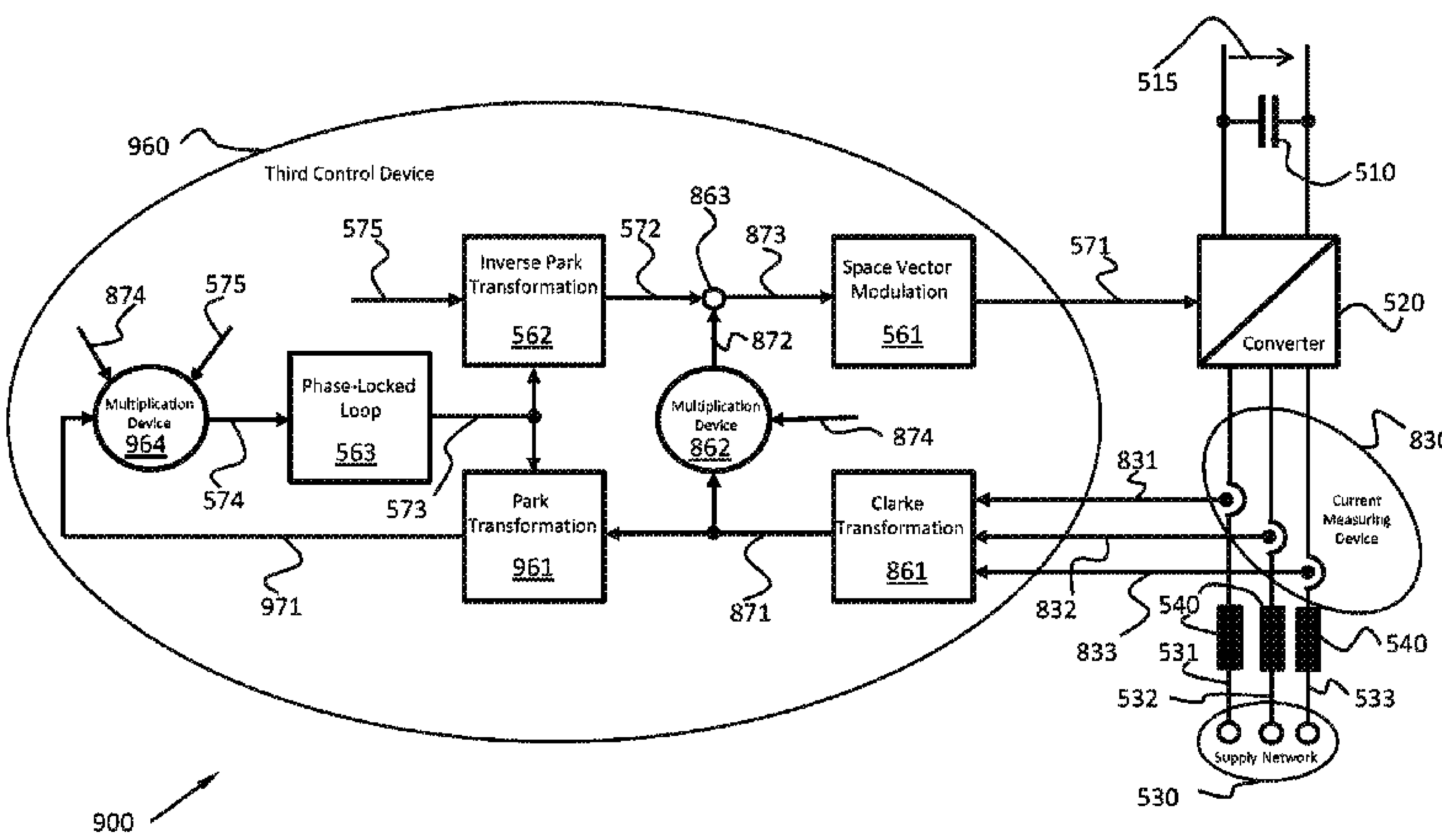

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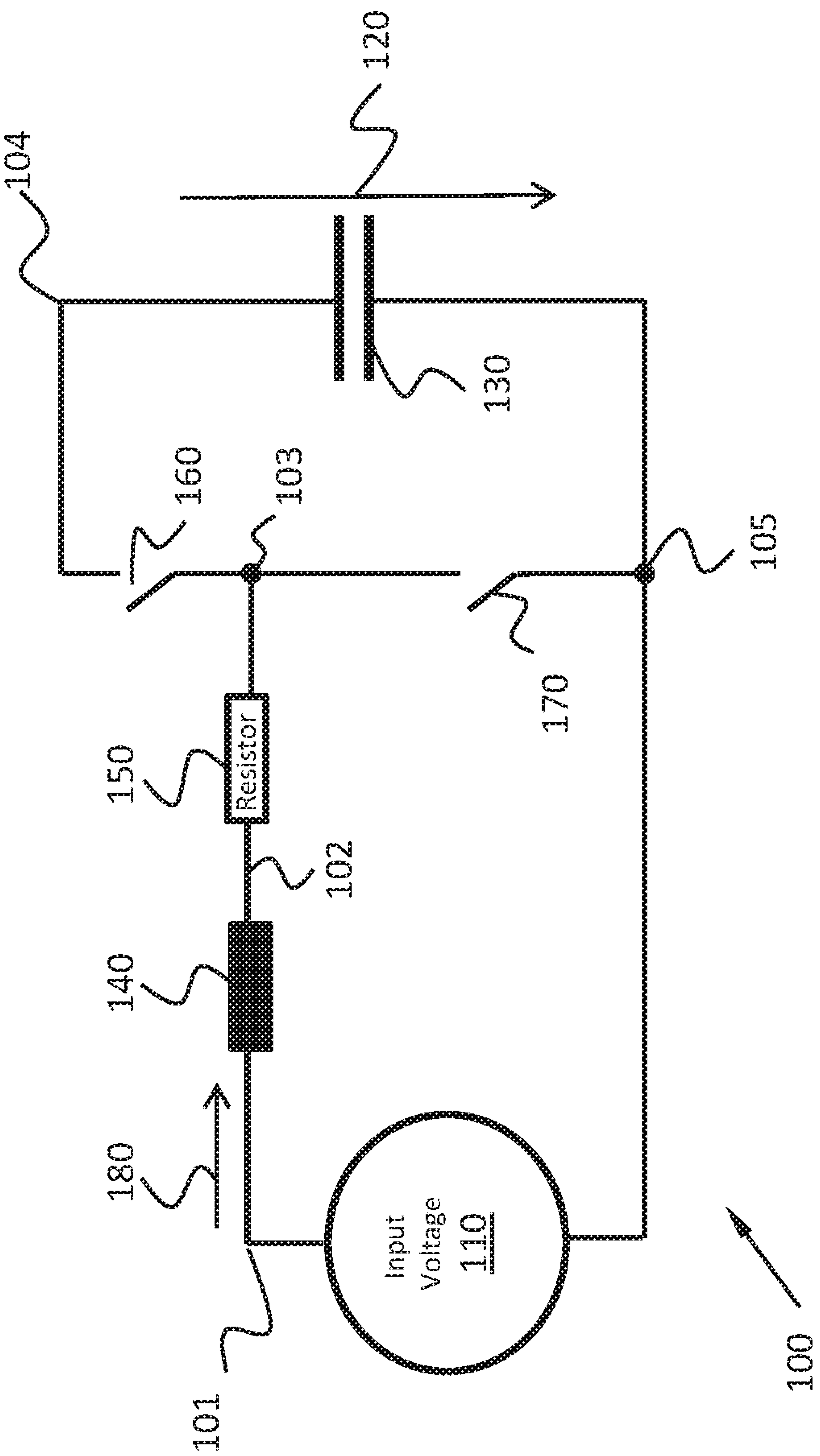
Fig. 1


Input
Voltage
110
Resistor
100
101
102
103
104
105
120
130
140
150
160
170
180

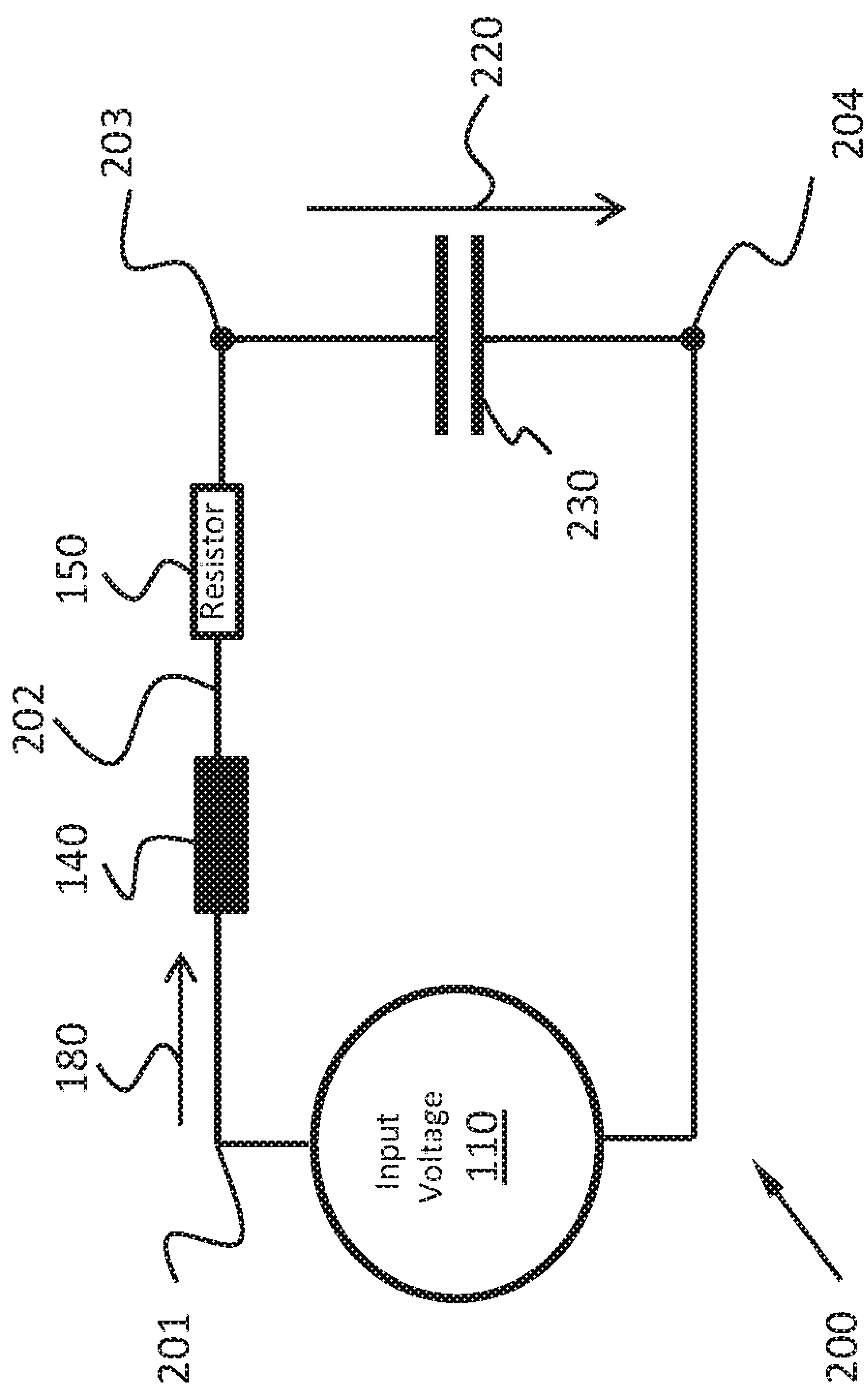
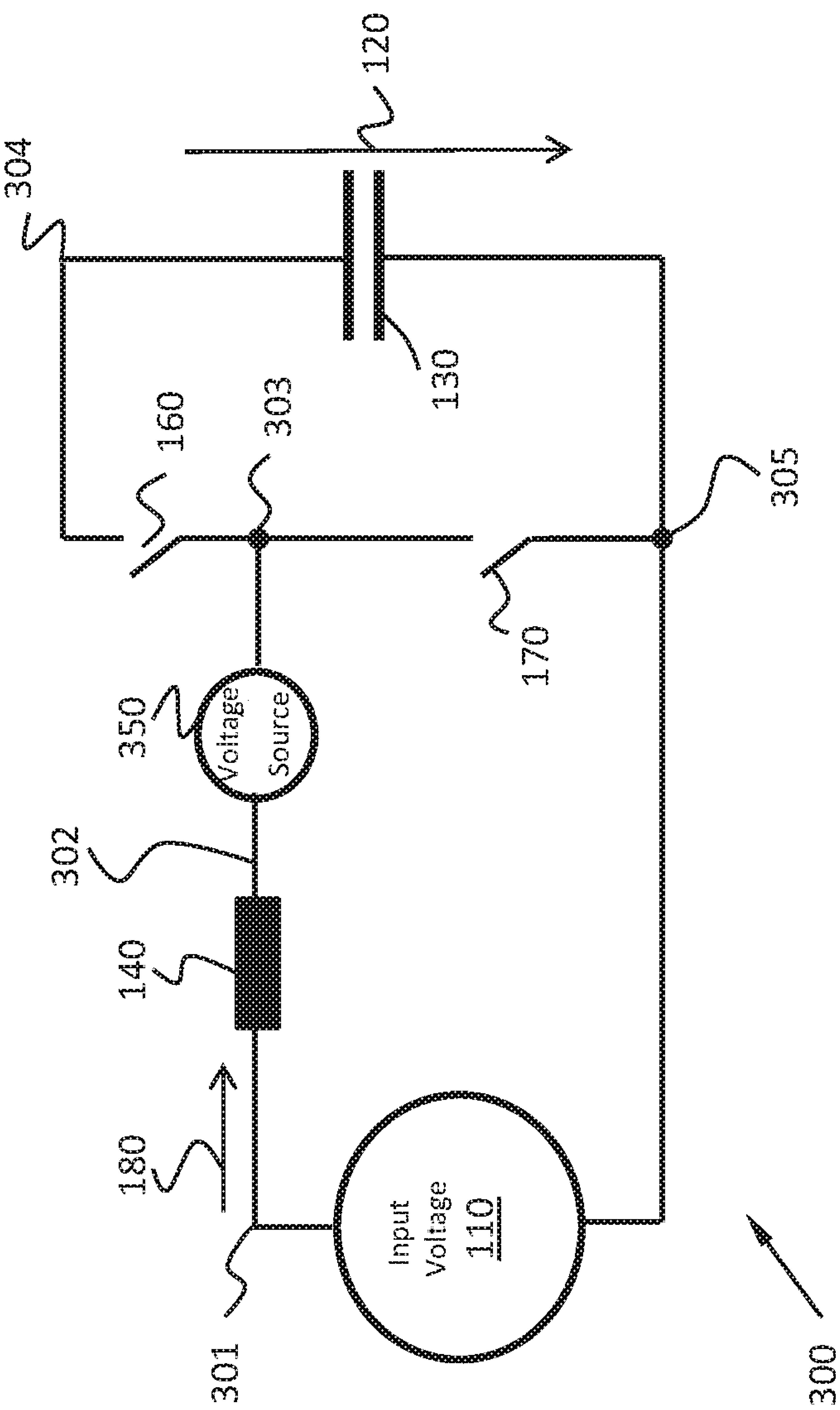

203
220
204
230
150
Resistor
202
140
180
Input
Voltage
110
201
200

Fig. 2

Fig.3


120
304
130
160
303
305
170
350
Voltage Source
302
140
180
Input Voltage 110
301
300

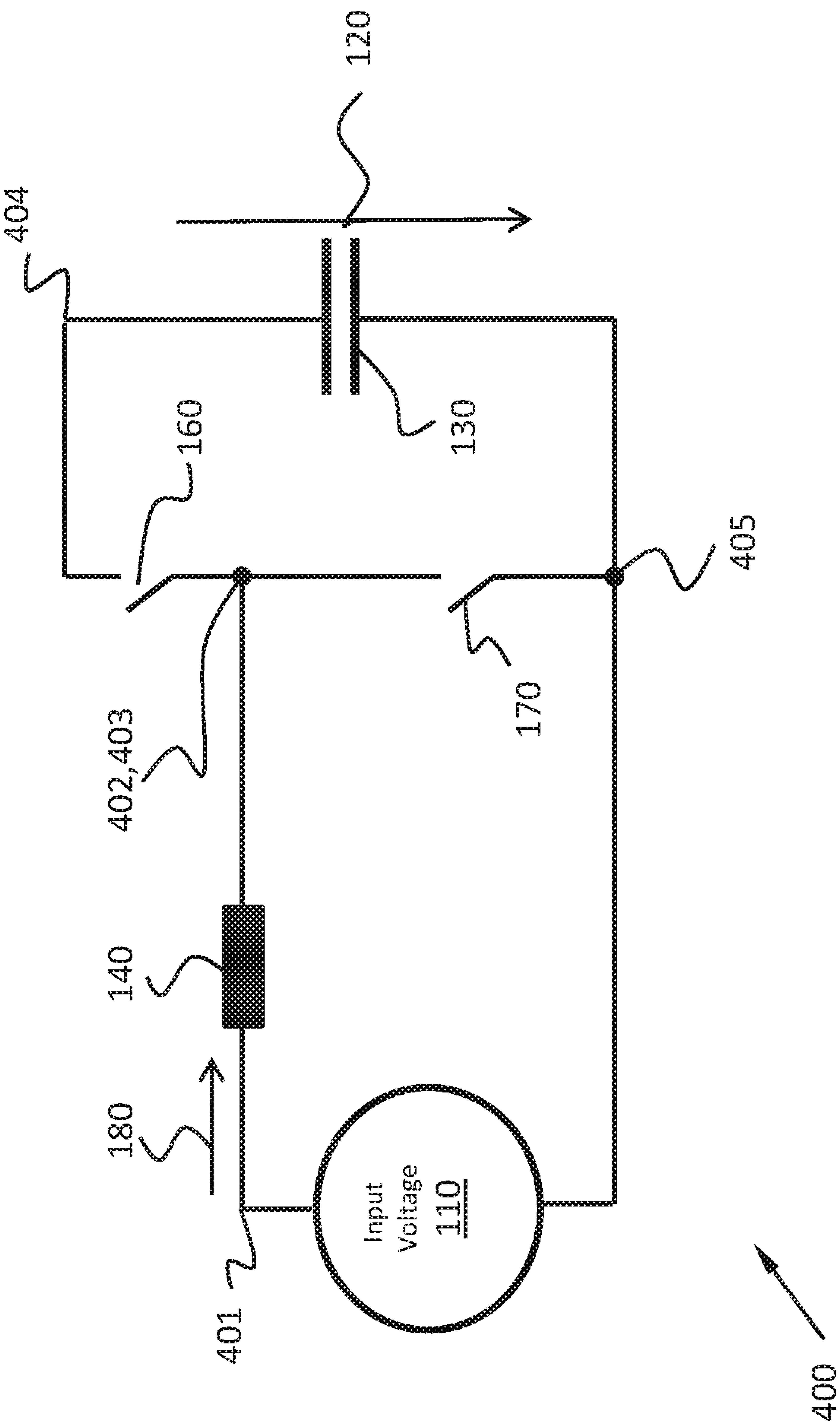

120
404
160
130
405
402,403
170
140
180
Input
Voltage
110
401
400

Fig.4

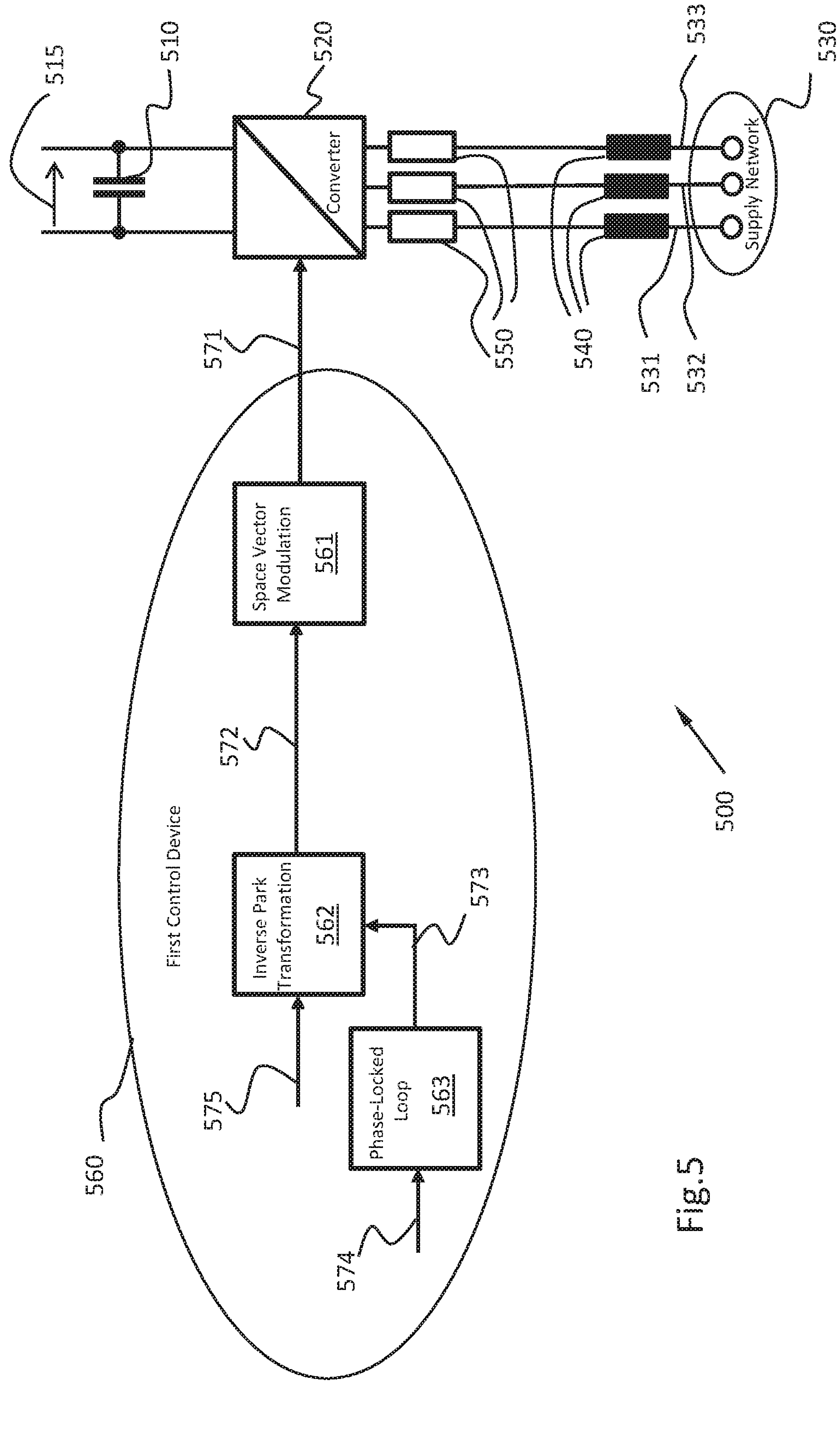

515
510
520
Converter
533
530
Supply Network
550
540
531
532
571
Space Vector Modulation
561
572
First Control Device
Inverse Park Transformation
562
573
500
575
Phase-Locked Loop
563
560
574

Fig.5

Fig.7

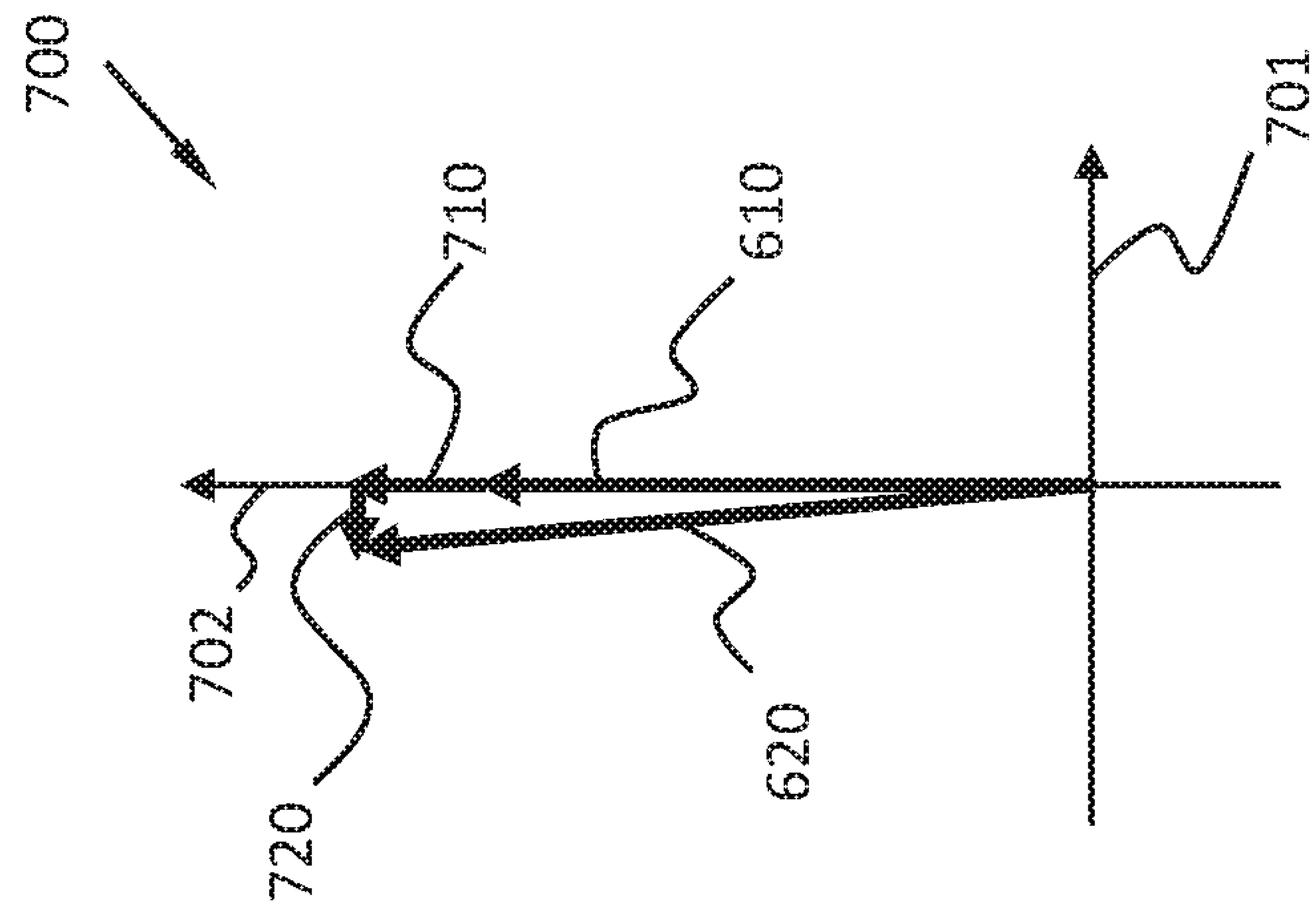

700
710
610
701
702
720
620

Fig.6

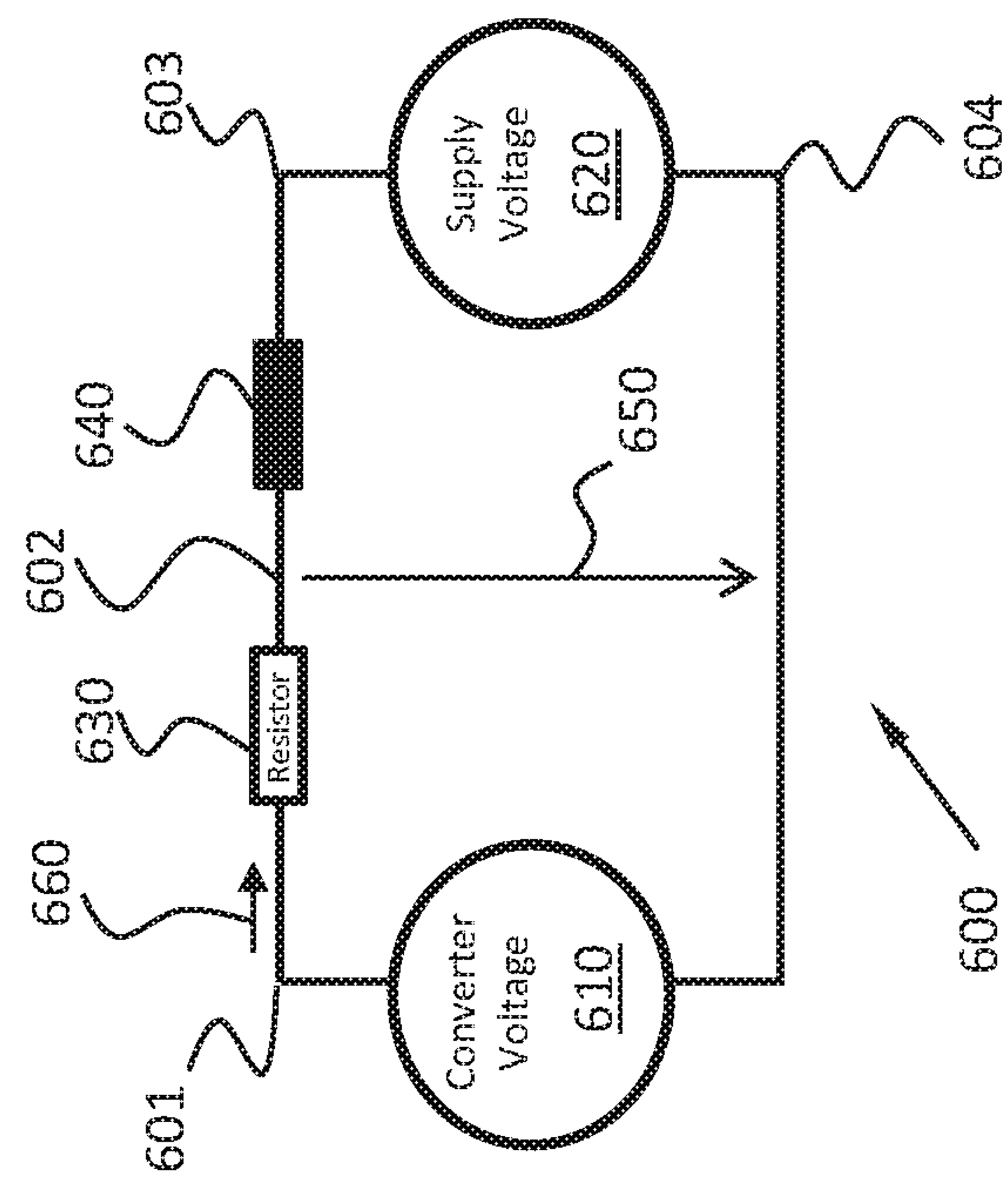

603
Supply Voltage
620
604
640
650
602
630
Resistor
660
Converter Voltage
610
601
600

Fig.8

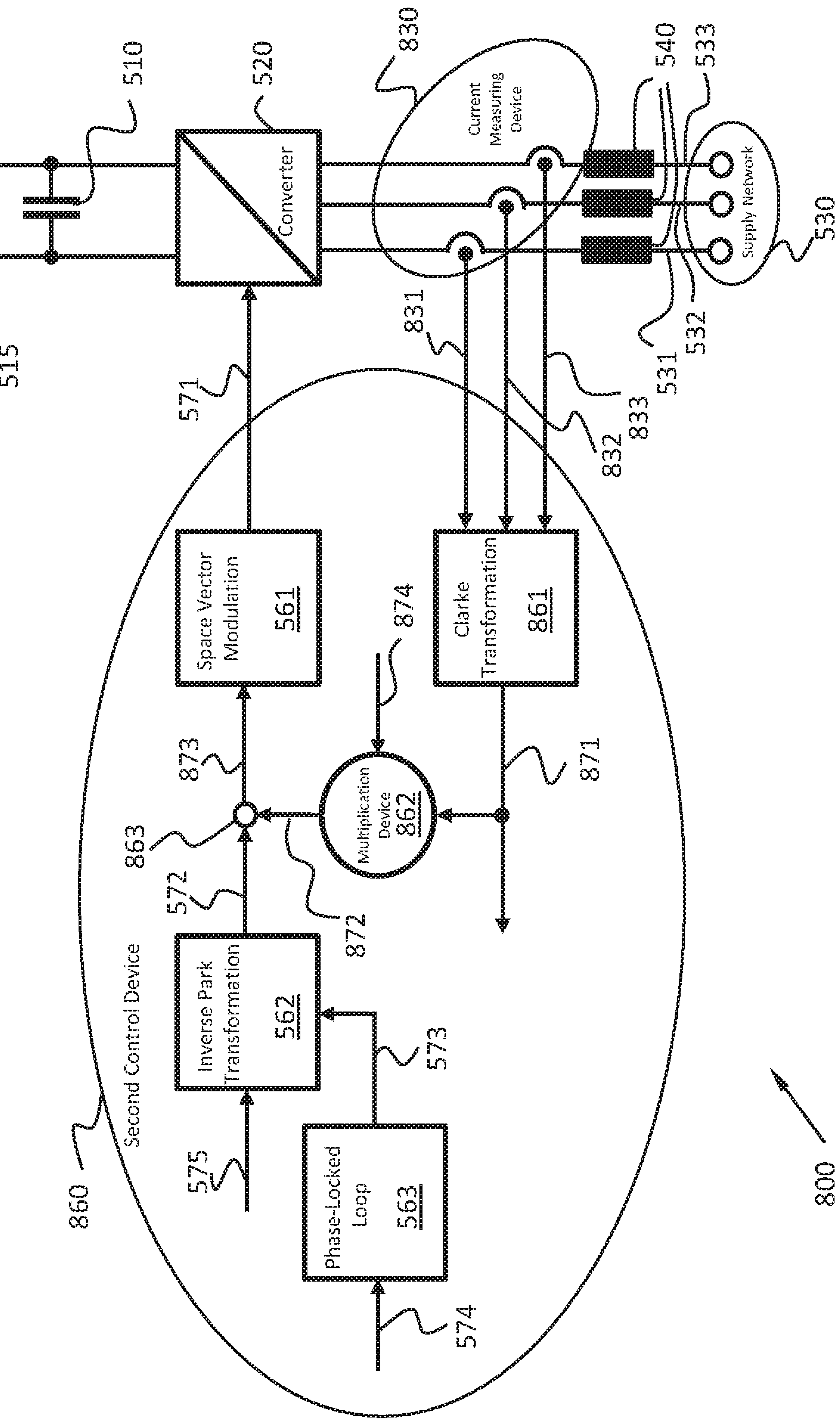

515
510
520
Converter
830
Current Measuring Device
540
533
530
Supply Network
531
532
831
832
833
571
Space Vector Modulation
561
Clarke Transformation
861
874
873
871
Multiplication Device
862
863
572
872
Inverse Park Transformation
562
573
Phase-Locked Loop
563
574
575
Second Control Device
860
800

Fig.9

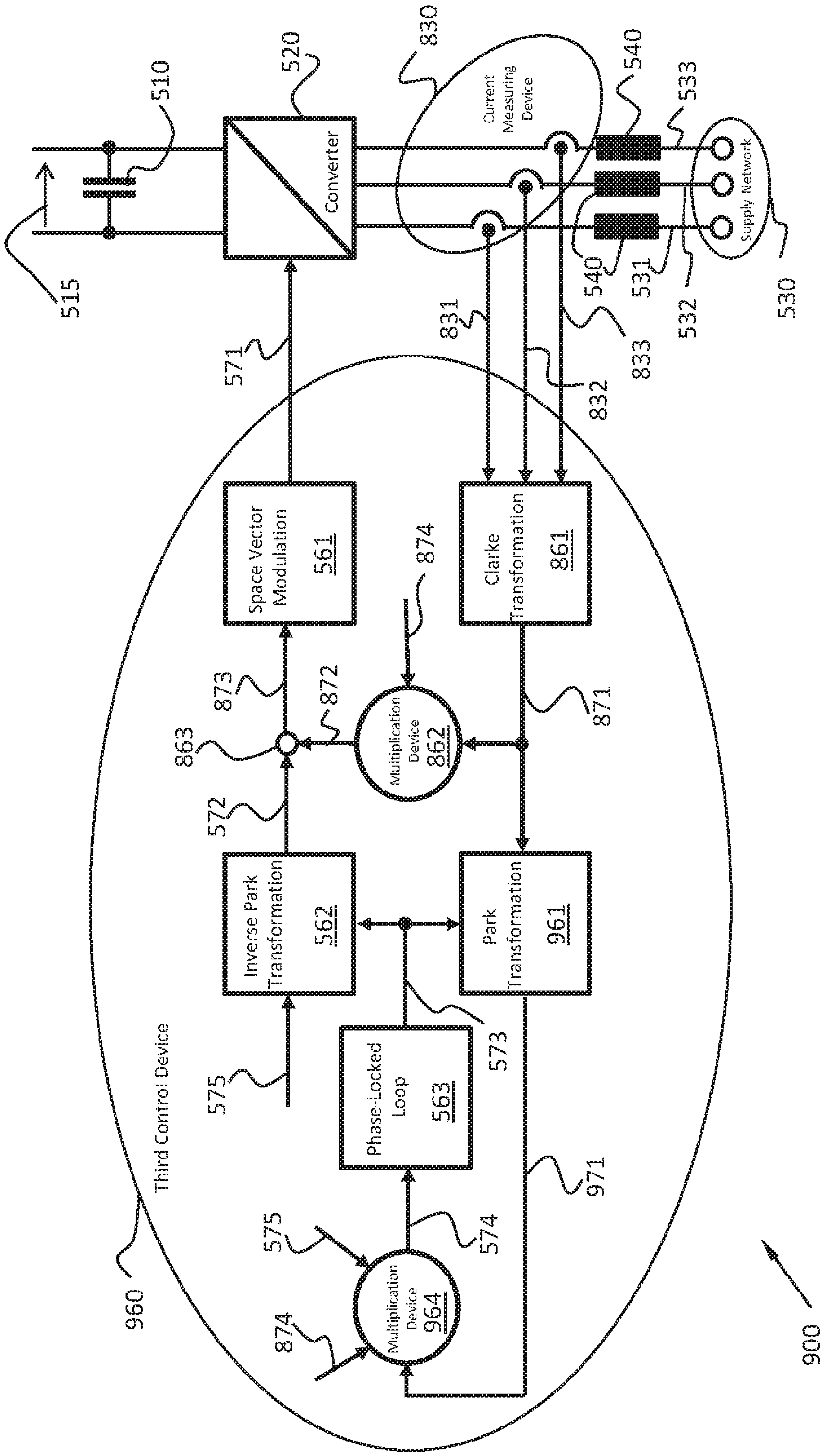
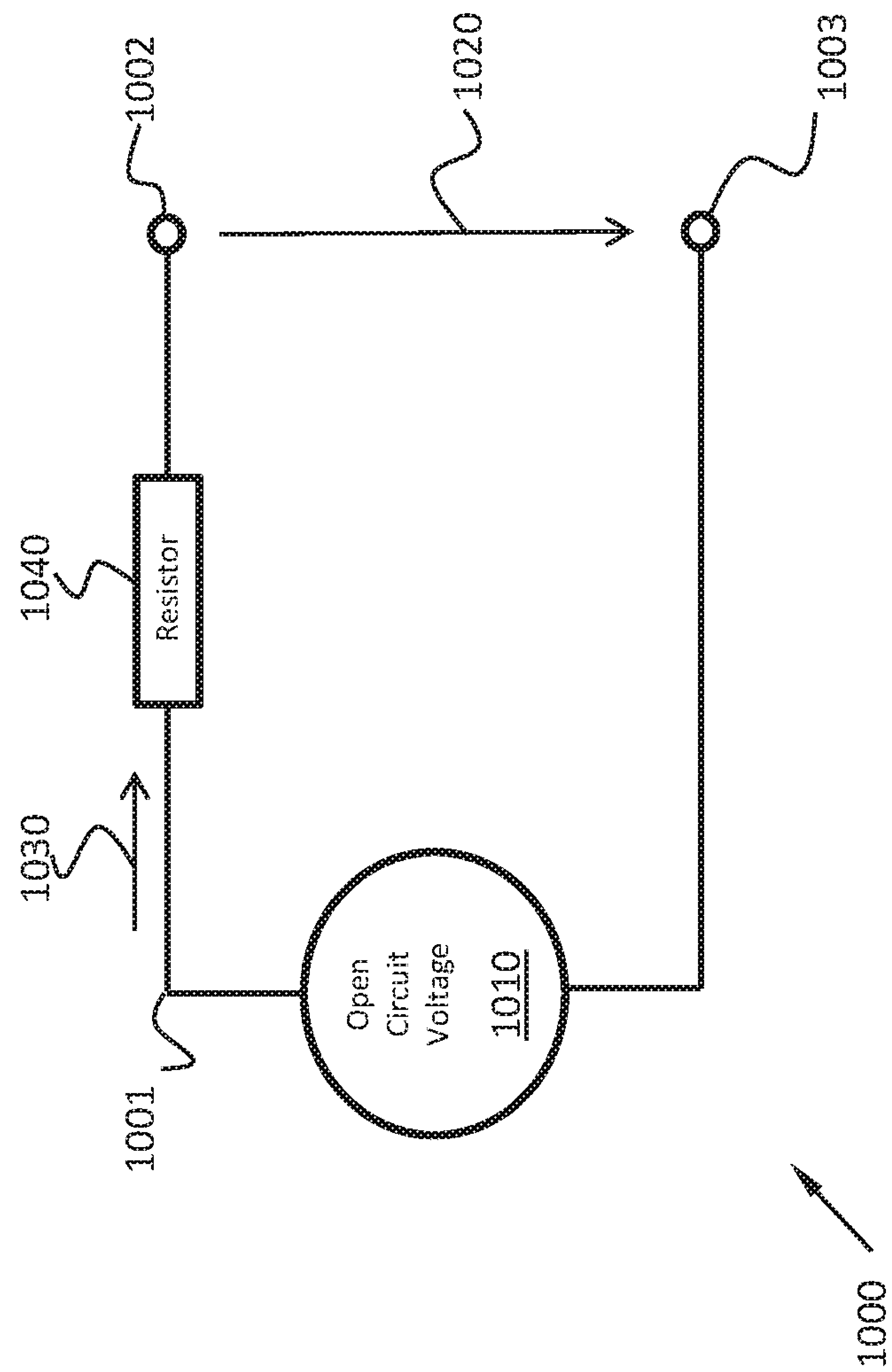

Converter
Current Measuring Device
Supply Network
Space Vector Modulation 561
Clarke Transformation 861
Multiplication Device 862
Inverse Park Transformation 562
Park Transformation 961
Phase-Locked Loop 563
Multiplication Device 964
Third Control Device
510
515
520
530
531
532
533
540
571
572
573
574
575
830
831
832
833
863
871
872
873
874
900
960
971

Fig.10


1002
1020
1003
1040
Resistor
1030
Open
Circuit
Voltage
1010
1001
1000

FEED-IN/FEEDBACK CONVERTER WITH PHASE CURRENT TRANSFORM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of International Patent Application No. PCT/EP2013/052076, filed on Feb. 1, 2013, which claims priority to German Patent Application No. DE 10 2012 203 204.5, filed on Mar. 1, 2012, the entire contents of both of which are incorporated herein by reference.

BACKGROUND

This disclosure relates generally to frequency conversion. In particular, the disclosure relates to methods for controlling frequency converters, and related circuit arrangements.

SUMMARY

The present invention refers to a method for controlling a frequency converter as well as to a circuit arrangement for generating an intermediate circuit voltage from a supply voltage of a three-phase supply network.

It is an object of the present invention to specify an improved method for controlling a frequency converter. This object is solved by a method of controlling a frequency converter having features of the claims. It is a further object of the present invention to provide an improved circuit arrangement for generating an intermediate circuit voltage from a supply voltage of a three-phase supply network. This object is solved by a circuit arrangement having features of the claims. Preferred embodiments are specified in the dependent claims.

A method of controlling a frequency converter comprises steps for measuring phase currents flowing in phase conductors of a three-phase supply network, for generating a third modulation space vector which comprises an angle that is synchronous to a supply voltage of the three-phase supply network, and an amplitude that depends on a determined modulation index and the measured phase currents, and for modulating the frequency converter according to the third modulation space vector. For generating the third modulation space vector, steps for generating a first modulation space vector that comprises the angle that is synchronous to the supply voltage of the three-phase supply network and the determined modulation index as an amplitude are carried out, and steps for generating the third modulation space vector depending on the first modulation space vector and on the measured phase currents. For generating the third modulation space vector, steps are carried out for implementing a Clarke transformation in order to transform the measured phase currents into a second current space vector, steps for multiplying the second current space vector by a determined virtual resistance to obtain a second modulation space vector, and for subtracting the second modulation space vector from the first modulation space vector to obtain the third modulation space vector.

A circuit arrangement for generating an intermediate circuit voltage from a supply voltage of a three-phase supply network comprises an intermediate circuit capacitor that may be connected to a first phase conductor, a second phase conductor and a third phase conductor of a three-phase supply network via a frequency converter and smoothing inductors, a measuring device for measuring phase currents flowing in the phase conductors and a control device that is provided for controlling the frequency converter. The control device is configured to generate a third modulation space vector that comprises an angle that is synchronous to a supply voltage of the three-phase supply network, and an amplitude that is dependent on a determined modulation index and on the measured phase currents, and is configured to modulate the frequency converter according to the third modulation space vector. The control device is configured to generate a first modulation space vector for generating the third modulation space vector, the first modulation space vector comprising the angle that is synchronous to the supply voltage of the three-phase supply network and the determined modulation index as an amplitude and the control device is configured to generate the third modulation space vector dependent on the first modulation space vector and on the measured phase currents. For generating the third modulation space vector, the control device is configured to transform the measured phase currents into a second current space vector via a Clarke transformation, to multiply the second current space vector by a determined virtual resistance to obtain a second modulation space vector, and to subtract the second modulation space vector from the first modulation space vector to obtain the third modulation space vector.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following, the invention will be explained in more detail on the basis of drawings in which:

FIG. **1** shows a circuit arrangement of a first two-quadrant chopper for explaining the mode of operation of a virtual internal resistor;

FIG. **2** depicts a first equivalent circuit diagram for the first two-quadrant chopper;

FIG. **3** shows a circuit arrangement of a second two-quadrant chopper without a lossy Resistor;

FIG. **4** shows a circuit arrangement of a third two-quadrant chopper for explaining a virtual internal resistor;

FIG. **5** depicts a block diagram of a first feed-in/feedback converter having a lossy internal resistor;

FIG. **6** depicts a one-phase second equivalent circuit diagram for explaining a network basic oscillation;

FIG. **7** shows a one-phase vector diagram for explaining the behaviour of amount/amplitude and phase of voltage and current;

FIG. **8** depicts a block diagram of a second feed-in/feedback converter having a virtual internal resistor;

FIG. **9** shows a block diagram of a third feed-in/feedback converter having a virtual internal resistor and a closed phase-locked loop; and

FIG. **10** depicts a schematic circuit arrangement for explaining the advantages of the third feed-in/feedback converter.

DETAILED DESCRIPTION

With reference to FIGS. **1** to **4**, the mode of operation of a virtual internal resistor is first of all explained on the basis of a two-quadrant chopper. A two-quadrant chopper is an electronic circuit that may be understood as a combination of a step-up chopper and a step-down chopper. In a two-quadrant chopper, energy may flow from a source to an appliance and from the appliance to the source.

FIG. **1** shows a circuit arrangement of a first two-quadrant chopper **100**. The circuit arrangement comprises a first node **101**, a second node **102**, a third node **103**, a fourth node **104** and a fifth node **105**. An input voltage **110** may be applied between the first node **101** and the fifth node **105**. A capacitor **130** is arranged between the fourth node **104** and the fifth node **105**, an output voltage **120** dropping over the capacitor **130**. An inductor **140** is arranged between the first node **101** and the second node **102**. A real, i.e. a lossy, resistor **150** is arranged between the second node **102** and the third node **103**. A first switch **160** is arranged between the third node **103** and the fourth node **104**. The first switch **160** might e.g. be configured as transistor. Between the third node **103** and the fifth node **105**, a second switch **170** is arranged that may e.g. as well be configured as transistor switch. An electric current **180** flows through the inductor **140**.

The output voltage **120** should be set to a multiple of the input voltage **110**, e.g. to the 1.25-fold of the input voltage **110**. For this purpose, the first switch **160** and the second switch **170** are opened and closed at a determined pulse duty factor a in an alternating manner. The inductor **140** serves as energy storage and for smoothing the current. The resistor **150** dampens the oscillatory, otherwise non-controlled system of inductor **140** and capacitor **130**. If the pulse duty factor a=1/1.25=0.8, the first switch **160** is thus switched on for 80% of a cycle duration and the second switch **170** is switched on for 20% of a cycle duration, the output voltage **120** adopts the 1.25-fold value of the input voltage **110**. In the case of a positive current **180** the first two-quadrant chopper **100** behaves as a step-up chopper and in the case of a negative current **180** as a step-down chopper.

If the switch frequency at which the first switch **160** and the second switch **170** are switched is considerably higher than the resonance frequency of the RLC resonator configured of resistor **150**, inductor **140** and capacitor **130**, the first two-quadrant chopper **100** of FIG. **1** may be depicted as a first equivalent circuit diagram **200** shown in FIG. **2**.

The first equivalent circuit diagram **200** comprises a first node **201**, a second node **202**, a third node **203** and a fourth node **204**. The input voltage **110** is applied between the first node **201** and the fourth node **204**. The inductor **140** is arranged between the first node **201** and the second node **202**, the current **180** flowing through the inductor **140**. The resistor **150** is arranged between the second node **202** and the third node **203**. An equivalent capacitor **230** is arranged between the third node **203** and the fourth node **204**, an equivalent capacitor voltage **220** dropping over the equivalent capacitor **230**.

The equivalent capacitor **230** comprises a capacity corresponding the capacity of the capacitor **130** of the first two-quadrant chopper **100** divided by the square of the pulse duty factor a. The equivalent capacitor voltage **220** dropping over the equivalent capacitor **230** corresponds to the product of the output voltage **120** of the first two-quadrant chopper **100** and the pulse duty factor a. The efficient capacity of the equivalent capacitor **230** is thus a function of the pulse duty factor.

FIG. **3** shows a circuit arrangement of a second two-quadrant chopper **300**. The circuit arrangement comprises a first node **301**, a second node **302**, a third node **303**, a fourth node **304** and a fifth node **305**. The input voltage **110** is applied between the first node **301** and the fifth node **305**. The capacitor **130** is arranged between the fourth node **304** and the fifth node **305**. The output voltage **120** in turn drops over the capacitor **130**. The inductor **140** is arranged between the first node **301** and the second node **302**, the current **180** flowing through the inductor **140**. The first switch **160** is arranged between the first node **303** and the fourth node **304**. The second switch **170** is arranged between the third node **303** and the fifth node **305**.

Instead of the lossy resistor **150**, the second two-quadrant chopper **300** comprises a controlled voltage source **350** between the second node **302** and the third node **303**. The controlled voltage source **350** applies a voltage u(t) between the second node **302** and the third node **303** depending on the current **180** flowing through the inductor **140**. In this manner, a virtual resistance R_v and a virtual inductance L_v may be programed:

$$u(t) = R_v \cdot i(t) + L_v \cdot \frac{d}{dt} i(t). \tag{1}$$

Here, i(t) indicates the value of the current **180** that is dependent on the time t.

The virtual resistance R_v and the virtual inductance L_v have the advantage that no loss of energy incurs at them.

FIG. **4** shows a circuit arrangement of a third two-quadrant chopper **400**. The circuit arrangement comprises a first node **401**, a second node **402**, a third node **403**, a fourth node **404** and a fifth node **405**. However, in the circuit arrangement of the third two-quadrant chopper **400**, the second node **402** and the third node **403** are one. The input voltage **110** is applied between the first node **401** and the fifth node **405**. The output voltage **120** drops over the capacitor **130** which is arranged between the fourth node **404** and the fifth node **405**. The inductor **140** is arranged between the first node **401** and the second node **402**, the current **180** flowing through the inductor **140**. The first switch **160** is arranged between the third node **403** and the fourth node **404**. The second switch **170** is arranged between the third node **403** and the fifth node **405**. Both the resistor **150** and the controlled voltage source **350** are omitted in the third two-quadrant chopper **400**.

Instead, in the third two-quadrant chopper **400**, the pulse duty factor a with which the first switch **160** and the second switch **170** are opened and closed in an alternating manner is modified as a function of the current **180**. For that purpose, the pulse duty factor a is chosen as

$$a(t) = 0,8 + i(t) \cdot \frac{R_v}{u_{dc}}, \tag{2}$$

in order to achieve the behaviour of a virtual resistance R_v. Here, i(t) is in turn the current **180** that is dependent on the time t. The yielding value of the output voltage **120** is indicated by u_{dc}.

The behaviour of a virtual inductance L_v might be achieved by a supplemental additive term:

$$L_v \cdot \frac{1}{u_{dc}} \cdot \frac{d}{dt} i(t). \tag{3}$$

For example a value R_v=5 Ω (ohm) may be chosen as virtual internal resistance.

The damping ratio ξ is

$$\xi = \frac{R_v}{2} \sqrt{\frac{C}{L}}. \tag{4}$$

Here, C is the (calculated) capacity of the capacitor **230** and L the inductance of the inductor **140**.

For a minimum damping, the maximum inductance L_{max} is

$$L_{max} = \frac{R_v^2 \cdot C}{4\xi^2}. \quad [5]$$

If the serial resonator of the third two-quadrant chopper is not sufficiently damped, the damping ratio ξ may be increased by an additional negative virtual inductance L_v. The RLC system of the third two-quadrant chopper is stable as long as the virtual resistance R_v is positive. A virtual inductance L_v may be negative however, the sum $L+L_v$ should be higher than 0 in order to guarantee the stability.

In the case of a capacity of the capacitor **230** of 2000 μF and a virtual resistance R_v=5 ohm, a maximum inductance L_{max} of 25 mH yields at a desired minimum damping ratio ξ of 0.707. The minimally-required inductance L_{min} for smoothing the current significantly yields from the allowed current ripple and the chosen switch frequency with which the switches **160**, **170** are switched.

In the following, the principle explained on the basis of FIGS. **1** to **4** is widened for a use in a three-phase supply network.

FIG. **5** shows a block diagram of a first feed-in/feedback converter **500**. The first feed-in/feedback converter **500** comprises a direct voltage intermediate circuit having an intermediate circuit capacitor **510**, an intermediate voltage **515** being applied over the intermediate circuit capacitor **510**. The intermediate circuit capacitor **510** is connected to a first phase **531**, a second phase **532** and a third phase **533** of a three-phase supply network **530** via a frequency converter **520**, three resistors **550** and three smoothing inductors **540**. The frequency converter **520** may e.g. be a three-level converter having a good efficiency. The first feed-in/feedback converter **500** comprises real, lossy resistors **550** for damping and for limiting the current.

The first feed-in/feedback converter **500** comprises a first control device **560** for controlling the frequency converter **520**. The first control device **560** may be configured as an analog circuit. Preferably, the first control device **560** is however implemented digitally.

The first control device **560** comprises a phase-locked loop **563** providing an angle **573** that is synchronous to the voltage of the first phase **531** of the three-phase supply network **530**. For this purpose, the phase-locked loop **563** is provided with an angle deviation **574**. The phase-locked loop **563** controls the angle **573** in such a way that the angle deviation **574** is minimized.

In the first control device **560**, a modulation index **575** is furthermore determined. The modulation index **575** and the angle **573** are provided to a device for an inverse Park transformation **562**. The device for the inverse Park transformation **562** generates a rotating first modulation space vector **572**. The first modulation space vector **572** comprises the angle **573** and a constant amplitude predetermined by the modulation index **575**.

The first modulation space vector **572** is provided to a device for space vector modulation **561** which generates control signals **571** therefrom with which the frequency converter **520** of the first feed-in/feedback converter **500** is controlled.

If the angle **573** provided by the phase-locked loop **563** is synchronous to the voltage of the first phase **531** of the three-phase supply network **530**, a supply output voltage of the frequency converter **520** approximately corresponds to the supply voltage. A remaining difference in voltage causes a flow of current which adjusts according to the resistors **550** and the inductors **540**.

For explaining the behaviour of absolute value and phase, FIG. **6** depicts a one-phase second equivalent circuit diagram **600** for the network basic oscillation of **50** Hz. The second equivalent circuit diagram **600** comprises a first node **601**, a second node **602**, a third node **603** and a fourth node **604**. A converter voltage **610** is applied between the first node **601** and the fourth node **604**. A supply voltage **620** is applied between the third node **603** and the fourth node **604**. A resistor **630** is arranged between the first node **601** and the second node **602**, a current **660** flowing through the resistor **630**. An inductor **640** is arranged between the second node **602** and the third node **603**. Between the second node **602** and the fourth node **604**, a voltage **650** is applied, the value of which is the difference between the converter voltage **610** and the product of the value of the current **660** and the resistance value of the resistor **630**. The current **660** flows then when the supply voltage **620** and the converter voltage **610** differ in phase or in amplitude.

FIG. **7** shows a vector diagram **700** having a reactive axis **701** and an active axis **702**. The absolute values and phases of the converter voltage **610**, the supply voltage **620**, the voltage **710** dropping over the resistor **630** and the voltage **720** dropping over the inductor **640** are shown.

FIG. **8** shows a schematic block diagram of a second feed-in/feedback converter **800**. The second feed-in/feedback converter **800** is a widening of the first feed-in/feedback converter **500** of FIG. **5**. The second feed-in/feedback converter **800** also comprises an intermediate circuit having an intermediate circuit capacitor **510**, an intermediate circuit voltage **515** being applied at the intermediate circuit capacitor **510**. The intermediate circuit capacitor **510** is connected to the first phase **531**, the second phase **532** and the third phase **533** of the three-phase supply network **530** via a frequency converter **520**. In turn, smoothing inductors **530** are provided between the phases **531**, **532**, **533** of the three-phase supply network **530**. The real, lossy resistors **550** of the first feed-in/feedback converter **500** of FIG. **5** are, however, emitted are replaced by a virtual resistor as will be explained in the following.

Instead of the first control device **560** of the first feed-in/feedback converter **500**, the second feed-in/feedback converter **800** comprises a second control device **860**. The second control device **860** may be configured as an analog circuit. Preferably, however, the second control device **860** is implemented in a digital manner.

The second control device **860** comprises a phase-locked loop **563**, an angle deviation **574** being provided to the phase-locked loop **563** and the phase-locked loop **563** outputting an angle **573** which is synchronous to the voltage of the first phase **531** of the three-phase supply network **530**. A device for an inverse Park transformation **652** again generates a first modulation space vector **572** having the angle **573** and an amplitude that is determined by a modulation index **575**.

The second feed-in/feedback converter **800** comprises a current measuring device **830** provided to measure a phase current **831** flowing in the first phase **531** of the three-phase supply network **530**, a second phase current **832** flowing in the second phase **532** and a third phase current **833** flowing in the third phase **533**.

The measured current values **831**, **832**, **833** are transferred to a device for a Clarke transformation **861** comprised by the second control device **860**. The device for the Clarke transformation **861** transforms the three-phase phase current **831**, **832**, **833** into a two-axis second current space vector **871**.

A first multiplication device **862** comprised by the second control device **860** multiplies the second current space vector **871** by a determined virtual resistor **874** to obtain a second modulation space vector **872**. The second modulation space vector **872** is subsequently subtracted from the first modulation space vector **872** by a subtraction device **863** to obtain a third modulation space vector **873**. Thereby, when having a sufficiently-high switching frequency of the converter, a behaviour that dynamically corresponds to the behaviour of real resistors is achieved. However, the virtual resistor **874** is advantageously not lossy.

The third modulation space vector **873** is provided to a device for space vector modulation **561** which generates control signals form the third modulation space vector **873**, the frequency converter **520** of the second feed-in/feedback converter **800** being controlled by means of said control signals **571**.

The power circuit of the second feed-in/feedback converter **800** consisting of the intermediate circuit capacitor **510**, the frequency converter **520** and the smoothing inductors **540** corresponds to the power circuit of a conventional feed-in/feedback converter. However, for controlling the frequency converter **520**, the virtual resistor **874** and the modulation index **575** are modulated instead of using a cascaded control. Preferably, the frequency converter is a IGBT inverted rectifier. The use of a three-level converter is particularly preferred.

FIG. **9** shows a block diagram of a third feed-in/feedback converter **900**. The third feed-in/feedback converter **900** is a further widening of the second feed-in/feedback converter **800** of FIG. **8** and of the first feed-in/feedback converter **500** of FIG. **5**.

The third feed-in/feedback converter **900** again comprises an intermediate circuit having intermediate circuit converter **510** over which an intermediate circuit voltage **515** drops. The intermediate circuit capacitor **510** is connected to a first phase **531**, a second phase **532** and a third phase **533** of a three-phase supply network **530** via a frequency converter **520**, preferably an IGBT inverted rectifier.

A current-measuring device **830** is provided to measure current value of a first phase current **831** flowing in the first phase **531**, of a second phase current **832** flowing in the second phase **532** and of a third phase current **533** flowing through a third phase **833**.

The third feed-in/feedback converter **900** comprises a third control device **960** instead of the second control device **860** of the second feed-in/feedback converter **800**. The third control device **960** can in turn be configured as an analog circuit. However, it is preferably implemented in a digital manner.

A phase-locked loop **563** of the third control device **960** receives an angle deviation **574** and generates an angle **573** that is synchronous to the voltage of the first phase **531** of the three-phase supply network. A device for an inverse Park transformation **562** generates a first modulation space vector **572** having the angle **573** and an amplitude that is determined by a determined modulation index **575**.

A device for a Clarke transformation **861** of the third control device **960** transforms the three-component phase current strength **831**, **832**, **833** into a two-component second current space vector **871**. A first multiplication device **862** multiplies the second current space vector **871** by a determined virtual resistor **874** to obtain a second modulation space vector **872**. A subtraction device **863** subtracts the second modulation space vector **872** from the first modulation space vector **572** to obtain a third modulation space vector **873**. A device for space vector modulation **561** generates control signals **571** from the third modulation space vector **873** by means of which the frequency converter **520** is controlled. Together with the intermediate circuit voltage, the supply output voltage of the frequency converter **520** yields.

In contrast to the second control device **860** of the second feed-in/feedback converter **800**, the third control device **960** of the third feed-in/feedback converter **900** additionally comprises a device for a Park transformation **961** that transforms the three-component measured phase current **831**, **832**, **833** into a two-component first current space vector **971**. Mathematically, it is alternatively possible to gain the first current space vector **971** from the second current space vector **871** gained by the device for a Clarke transformation **861**, which is why the device for a Park transformation **961** is depicted as subsequent to the device for a Clarke transformation **861** in the block diagram of FIG. **9**.

The first current space vector **971** comprises an active component and a reactive component. The active component is frequently marked by an index d (direct axis) and the reactive component by an index q (quadrature axis). The request posed to the phase-locked loop **563** to adjust the angle **573** in such a way that the angle **573** is synchronous to the first phase **531** of the three-phase supply network **530** corresponds to the request that the reactive component of the first current space vector **971** vanishes, i.e. that it is adjusted to zero. If this is the case, the first modulation space vector **572** and the phase current **831**, **832**, **833** are in phase. Optionally, a phase shift differing from zero might, however, also be provided.

In order to set the reactive component of the first current space vector **971** to zero, said reactive component is multiplied by a quotient of the determined virtual resistor **874** and the determined modulation index **575** by a second multiplication device **964** of the second control device **960** in order to attain the angle deviation **574**. Said angle deviation **574** is provided to the phase-locked loop **563**. Thus, the phase-locked loop in the third control device **960** of the third feed-in/feedback converter **900** is closed.

The third feed-in/feedback converter **900** can be initialized with a pre-charge circuit at the beginning of operation, as is obvious to a person skilled in the art and is not shown here in detail.

In the third feed-in/feedback converter **900**, an active current or voltage control in the intermediate circuit is not required. Instead, the intermediate circuit voltage **515** adjusts in a non-controlled manner depending on the voltage of the three-phase supply network **530** and a load current in the intermediate circuit. The desired behaviour may therein be adjusted by parameterization of the virtual resistor **874** and the modulation index **575**. This is in the following explained on the basis of FIG. **10**.

FIG. **10** shows a schematic depiction of an intermediate circuit **1000**. The circuit comprises a first node **1001**, a second node **1002** and a third node **1003**.

Between the first node **1001** and the third node **1003**, an open-circuit voltage **1010** is applied that corresponds to the modulation index **575** of the third feed-in/feedback converter **900**. Said open-circuit voltage **1010** is chosen to be higher than the absolute value of the supply voltage of the three-phase supply network **530**. For example, the open-circuit voltage **1010** may amount to the 1.6-fold amplitude of the supply voltage. In a three-phase supply network **530** having 400 V, the open-circuit voltage would e.g. amount to 640 V.

Between the first node **1001** and the second node **1002**, a virtual resistor **1040** is arranged that corresponds to the virtual resistor **874** of the third feed-in/feedback converter **900**. A load current **1030** flows through the virtual resistor **1040**.

Between the second node **1002** and the third node **1003**, an intermediate circuit **1020** is applied that corresponds to the intermediate circuit voltage **515** of the third feed-in/feedback converter **900**.

If an exemplary value of 5 ohm is chosen for the virtual resistor **1040**, the intermediate circuit voltage **1020** decreases by 5 V per Ampère according to Ohm's law. In the case of a feedback of energy, i.e. a negative load current **1030**, the intermediate circuit voltage **1020** would accordingly increase proportionally to the load current **1030**. Thus, the intermediate circuit voltage **1020** sets depending on the open-circuit voltage **1010** and the load current **1030**.

By the choice of the values of the virtual resistor **1040**, respectively the virtual resistor **874** of the third feed-in/feedback converter **900** and the open-circuit voltage **1010**, respectively the modulation index **575** of the third feed-in/feedback converter **900**, the compliance of the intermediate circuit voltage **1020**, respectively of the third intermediate circuit voltage **515** of the third feed-in/feedback converter **900** may be set. The value of the virtual resistor **1040**, **874** indicates to which extent the intermediate circuit voltage **1020**, **515** decreases or increases with the load current **1030**.

If the intermediate voltage **1020**, **515** reaches a determined maximum value, e.g. 740 V at a load current of −20 A and a virtual resistance of 5 ohm, a load resistor that may optionally be connected may impede a further increase of the intermediate circuit voltage **1020**, **515**. If however, the intermediate circuit voltage **1020**, **515** reaches a determined minimum value of e.g. 540 V at a load current of +20 A and a virtual resistance of 5 ohm, a diode rectifier switched in parallel without network inductance may take over the additionally-required current. The diode rectifier and the load resistor may either be provided within the third feed-in/feedback converter **900** or they may be connected in a modular manner or as individual modules.

The voltage spike of the intermediate circuit voltage **515** that is allowed in the third feed-in/feedback converter **900** advantageously makes it possible that short-term peak performances are stored in the intermediate circuit capacitor **510** or are taken from the intermediate circuit capacitor **510**. If e.g. the intermediate circuit capacitor **510** comprises a capacity of 1000 μF and if an increase of the intermediate circuit voltage **515** from a value of 640 V up to a value of 740 V is allowed, an energy of 69 Ws may be stored in the intermediate circuit capacitor **510**.

A further advantage of the third feed-in/feedback converter **900** is that several third feed-in/feedback converters **900** may be switched in parallel without limitation. An electric current is then divided up in load direction as well as in feedback direction according to the virtual resistors **874** of the third feed-in/feedback converter **900**. This also applies for the devices of differing installation size supplied by the feed-in/feedback converter **900** if the virtual resistors **874** of the third feed-in/feedback converters **900** are respectively configured in an inversely proportional manner to the effective outputs of said devices.

The resulting total resistance yields from the parallel connection of the virtual resistors **874** of the third feed-in/feedback converters **900**.

A further advantage of the third feed-in/feedback converter **900** is that individual third feed-in/feedback converters **900** may be connected or disconnected according to requirements during a running operation. This allows for operating the third feed-in/feedback converters **900** according to requirements at a respectively optimal efficiency.

A further advantage of the third feed-in/feedback converter **900** is that it does not comprise any tendency to oscillate. This also applies for their use in soft networks.

The third feed-in/feedback converter **900** may also be operated in a one-phase manner. For this purpose, only an adaption of the phase-locked loop of the third control device **960** of the third feed-in/feedback converter **900** is required which is known to a person skilled in the art.

Advantageously, the described method for controlling the frequency converter does not require an active current or voltage control. Instead, in this method, an intermediate circuit voltage is adjusted relative to a voltage of the three-phase supply voltage in a non-controlled manner. Thereby, the effort required for carrying out said method is advantageously reduced and an efficiency during operation of the frequency converter that is improved compared to the state of the art may be achieved. Also, it is advantageous that a supply output voltage of the frequency converter approximates the supply voltage of the three-phase supply network with increasing phase currents, the phase currents thus being automatically delimited.

Advantageously, the intermediate circuit voltage adjusts in a non-controlled manner relatively to the supply voltage of the three-phase supply network with a virtual resistor. Advantageously, the method allows for the intermediate circuit voltage to decrease proportionally to a load current depending on the value of the virtual resistance, or in the case of a feedback, increase, corresponding to Ohm's law. This behaviour has the advantage that when a pre-settable maximum value of the intermediate circuit voltage is reached, a load resistor that may optionally be connected may prevent a further voltage increase. Furthermore, when reaching a pre-settable maximum load current, i.e. when reaching a minimum value of the intermediate circuit voltage determined by the supply voltage, the virtual resistance and the predetermined maximum load voltage, a diode rectification without network inductance that is switched in parallel may receive the additionally-required current. A further advantage of the method is that by allowing a voltage rise in the direct current intermediate circuit, momentary peak performances may be stored in the intermediate circuit capacitor or may be taken from the same.

A particular advantage of the method is that feed-in/feedback converters with frequency converters controlled by the method may be switched in parallel in an unlimited manner. This allows for connecting and disconnecting individual modules during running operation, depending on demands, a particularly favourable efficiency in all performance situations resulting thereof.

A further advantage of said method for controlling a frequency converter is its robustness as a result of which no or only a small tendency to oscillate is developed also for soft networks.

Preferably, for generating the first modulation space vector, steps for implementing a Park transformation are carried out using the angle in order to transform the measured phase currents into a first current space vector, for controlling the angle in such a way that a reactive-current component of the first current space vector vanishes, and for generating the first modulation space vector which comprises the angle and the determined modulation index as an amplitude, by means of an inverse Park transformation. Advantageously, this is a simple possibility of generating the first modulation space vector with an angle that is synchronous to the supply voltage of the three-phase supply network.

In a variant of the method, the reactive-current component of the first current space vector is multiplied by a quotient of a determined virtual resistance and the determined modulation index to obtain an angle deviation, wherein the angle deviation is provided to a phase-locked loop for controlling the angle. Advantageously, controlling the phase-locked loop then has the result that a reactive-current component of the first current space vector always comprises a negligible value.

In an additional variant of the method, a control signal for the frequency converter is generated from the third modulation space vector by means of a space vector modulation. The supply output voltage of the frequency converter then results from the third modulation space vector and the intermediate circuit voltage. Advantageously, the frequency converter itself may then be configured in a known manner, e.g. as IGBT inverted rectifier.

Advantageously, the circuit arrangement described above does not require any active current or voltage control. Instead, in this circuit arrangement, an intermediate circuit voltage sets relatively to a voltage of the three-phase supply network in a non-controlled manner. Thereby, the complexity of the circuit arrangement is advantageously reduced and an efficiency that is improved compared to the state of the art may be achieved. Advantageously, a supply output voltage of the frequency converter approximates the supply voltage of the three-phase supply network with increasing phase currents, the phase currents thus being automatically delimited.

Advantageously, in this circuit arrangement, the intermediate circuit voltage decreases or, in the case of a feedback, increases proportionally to a load current, depending on the value of the virtual resistance according to Ohm's law. This behaviour has the advantage that when a pre-settable maximum value of the intermediate circuit voltage is reached, a load resistor that may optionally be connected may prevent a further voltage increase. Furthermore, when reaching a pre-settable maximum load current, i.e. when reaching a minimum value of the intermediate circuit voltage determined by the supply voltage, the virtual resistance and the predetermined maximum load voltage, a diode rectification without network inductance that is switched in parallel may receive the additionally-required current. A further advantage is that by means of the voltage rise in the direct voltage intermediate circuit which is now allowed, momentary peak performances may be stored in the intermediate circuit capacitor or may be taken from the same.

A particular advantage of the circuit arrangement is that several of said circuit arrangements may be switched in parallel in an unlimited manner. This allows for connecting and disconnecting individual modules during running operation, depending on demands, a particularly favourable efficiency in all performance situations resulting thereof.

A further advantage of the circuit arrangement is its robustness. Also for soft networks, it comprises no or only a small tendency to oscillate.

In a preferred embodiment of the circuit arrangement, for generating the first modulation space vector via a Park transformation, the control device is configured to transform the measured phase currents into a first current space vector using the angle of the measured phase currents, to control the angle by means of a phase-locked loop in such a way that a reactive-current component of the first current space vector vanishes, and to generate the first modulation space vector which comprises the angle and the determined modulation index as an amplitude by means of an inverse Park transformation. Advantageously, this is a simple possibility of generating the first modulation space vector having an angle that is synchronous to the supply voltage of the three-phase supply network.

In a variant of the circuit arrangement, the control device is configured to multiply the reactive-current component of the current space vector by a quotient of a determined virtual resistance and the determined modulation index to obtain an angle deviation. The control device is further configured to feed the angle deviation to the phase-locked loop. Advantageously, controlling the phase-locked loop then causes a reactive-current component of the first current space vector to always comprise a negligible value.

In an additional variant of the circuit arrangement, the control device is configured to generate a control signal for the frequency converter from a modulation space vector by means of a space vector modulation. Advantageously, the frequency converter itself may then be configured in a known manner, e.g. as IGBT inverted rectifier.

In a preferred embodiment of the circuit arrangement, the frequency converter is an IGBT inverted rectifier. IGBT inverted rectifiers are advantageously suitable for switching high performances.

The invention claimed is:

1. A method for controlling a frequency converter, wherein the method comprises the following steps:

- measuring phase currents flowing in phase conductors of a three-phase supply network;
- generating a first modulation space vector that is in phase with the phase currents and that comprises an angle that is synchronous to a supply voltage of the three-Phase supply network and that comprises a determined modulation index as an amplitude;
- conducting a Clarke transformation to transform the measured phase currents into a second current space vector;
- multiplying the second current space vector by a determined virtual resistance to obtain a second modulation space vector;
- subtracting the second modulation space vector from the first modulation space vector to obtain a third modulation space vector; and
- modulating the frequency converter according to the third modulation space vector;
- wherein generating the first modulation space vector comprises the following steps:
  - conducting a Park transformation using the angle in order to transform the measured phase currents into a first current space vector;
  - controlling the angle in such a way that a reactive-current component of the first current space vector takes a determined value; and
  - generating the first modulation space vector that comprises the angle and the determined modulation index as an amplitude, by means of an inverse Park transformation.

2. The method according to claim **1**, wherein the reactive-current component of the first current space vector is multiplied by a quotient of a determined virtual resistance and the determined modulation index to obtain an angle deviation, and to provide the angle deviation to a phase-locked loop in order to control the angle.

3. The method according to claim 1, wherein a control signal for the frequency converter is generated from the third modulation space vector by means of a space vector modulation.

4. A circuit arrangement for generating an intermediate circuit voltage from a supply voltage of a three-phase supply network, the circuit arrangement comprising:

an intermediate circuit capacitor configured for being connected to a first phase conductor, a second phase conductor and a third phase conductor of a three-phase supply network via a frequency converter and smoothing inductors;

a measuring device for measuring phase currents flowing in the phase conductors; and

a control device that is provided for controlling the frequency converter;

wherein the control device is configured to:

generate a first modulation space vector that is in phase with the phase currents and that comprises an angle that is synchronous to a supply voltage of the three-phase supply network and that comprises a determined modulation index as an amplitude,

transform the measured phase currents into a second current space vector via a Clarke transformation,

multiply the second current space vector by a determined virtual resistor to obtain a second modulation space vector,

subtract the second modulation space vector from the first modulation space vector to obtain a third modulation space vector, and

modulate the frequency converter according to the third modulation space vector;

wherein the control device is configured to:

generate the first modulation space vector, to transform the measured phase currents into a first current space vector via a Park transformation using the angle,

control the angle by means of a phase-locked loop in such a way that a reactive-current component of the first current space vector takes a determined value, and

generate the first modulation space vector via an inverse Park transformation, the first modulation space vector comprising the angle and the determined modulation index as an amplitude.

5. The circuit arrangement according to claim 4, wherein the control device is configured to:

multiply the reactive-current component of the first current space vector by a quotient of a determined virtual resistance and the determined modulation index to obtain an angle deviation , and

provide the angle deviation to the phase-locked loop.

6. The circuit arrangement according to claim 4, wherein the control device is configured to generate a control signal for the frequency converter from the third modulation space vector.

7. The circuit arrangement according to claim 4, wherein the frequency converter is an IGBT inverted rectifier.

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